

III. *Magnetical Experiments and Observations.**By Mr. Tiberius Cavallo, F. R. S.*

(The Lecture founded by the late HENRY BAKER, Esq. F.R.S.)

Read November 24, 1785.

THE object of this lecture is to shew the properties of some metallic substances with respect to magnetism; and the experiments herein related seem to ascertain some new and remarkable facts.

The magnetic properties have been generally thought to belong only to iron, or to those substances which contained that metal; comprehending under the general name of iron not only the metal commonly so called, but likewise its more perfect and more imperfect states, *viz.* steel, iron ores, amongst which is considered the magnet, and the calces of iron, excepting only those which are very much dephlogisticated, for they possess no magnetic property whatsoever. Some other metallic substances, and especially platina, brass, and nickel, on which the magnet has some action, were thought to be magnetic so far as they contained some portion of iron, the presence of which may be manifested by chemical methods in many cases, but not always; because the quantity of iron may be so excessively small in proportion to the weight of the other metal in which it is concealed, as not to be discoverable by chemical analysis, and yet it may be sufficient to affect the magnetic needle.

needle. The following experiment will shew, that an exceedingly small quantity of iron will render a body sensibly magnetic.

Having chosen a piece of Turkey-stone, which weighed about an ounce, I examined it by a very sensible magnetic needle, and found that it had not the least degree of magnetism, the needle not being moved from its usual direction by the vicinity of any part of the surface of the stone; I then weighed a piece of steel with a pair of scales that turned with the twentieth part of a grain, and afterwards drew one end of it over the surface of the stone in various directions. This done, the piece of steel was weighed again, and was found to have lost so small a part of its weight as not to be discernible by that pair of scales; yet the Turkey-stone, which had acquired only that small quantity of steel, affected the magnetic needle very sensibly. Chemistry seems not to afford any means by which so small a quantity of iron may be decisively detected in a body that weighs one ounce. Hence it follows, that though no iron is to be discovered in a body by chemical methods, yet it should not be concluded, that the said body, if it affect the magnetic needle, does not own its magnetism to some small quantity of iron concealed in its substance.

Nickel is a metallic substance which has been suspected to be capable of acquiring some degree of magnetism independent of iron; and this suspicion has been founded upon observing, that nickel retained its magnetism after having been repeatedly purified*. There are, however, persons who have denied the magnetism of purified nickel; and I have seen some pieces of it which did not in the least affect the magnetic needle. It is probable, that those pieces were not pure nickel, and perhaps

* See KIRWAN's Mineralogy, p. 342. and 367.

some cobalt was contained in them; but I see no reason why the nickel, when alloyed with a little cobalt, should shew no magnetism, if that property does really belong essentially to it.

The greatest number of my experiments are relative to the properties of brass; and they seem to prove, that this compound metal, which is often magnetic, does not owe its magnetism to iron, but to some particular configuration of its component particles, occasioned by the usual method of hardening it, which is by hammering.

In some specimens of brass, and especially in that which has often passed from the work-shop to the furnace, and from the latter to the former, there are sometimes pieces of iron sensible not only to the magnet, or the chemical analysis, but even to the sight, which render the brass strongly magnetic. But the brass generally used in my experiments was such as, when quite soft, it had no sensible degree of magnetism.

Before we begin with the narration of those experiments, it will be proper to describe the magnetic needle I generally used, which is suspended in a particular manner; and which may be useful to persons who are fond of making magnetic experiments, not only for its sensibility, but likewise for the simplicity of its construction.

Experience having shewn, that large magnetic needles are not proper for experiments wherein a very small degree of magnetism must be ascertained, and the free motion of the usual small needles being proportionally more obstructed by the nature of their suspension, even when furnished with agate caps, I endeavoured to contrive a sort of suspension which might answer the purpose better than the needles suspended in the usual manner; and, after several attempts, at last I constructed a chain
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of horse-hair, consisting of five or six links, to which the needle was suspended. Each link is about three-quarters of an inch in diameter; and the extremities of each piece of hair, which is formed in a ring, are joined by a knot, and secured by a little sealing-wax. The link on one end of this chain is suspended to a pin in a proper frame, or any support that may be at hand; and to the link of the other extremity which lies lowermost, a piece of fine silver wire is hooked. This wire is about an inch and a half long, and its lower extremity is fastened round a small and cylindrical piece of cork, through which a common sewing needle, made magnetic, is thrust horizontally. Thus the magnetic needle is suspended by a hair-chain, the links of which, on account of the smoothness and lightness of the hair, move very freely in each other, and allow the needle more than a whole revolution round its centre, with so small a degree of friction as may be considered next to nothing. By comparing this needle with others of the best sort in use, I find the former to be much more sensible; for when bodies which have an exceedingly small magnetic power are tried, this needle will be frequently attracted by them when the others are not sensibly affected.

In order to try farther the delicacy of such suspension, I placed a piece of looking-glass under the needle, and nearly horizontal, so that the image of the needle was seen in it. Now, as a fine line had been previously marked on the glass, things were so disposed as that the image of the needle might coincide with the line marked on the glass, the eye being placed in a proper point of view; afterwards, by shaking the needle either very gently or very quickly, I repeatedly endeavoured to place it out of the magnetic meridian; but every

endeavour proved ineffectual, for the needle constantly settled in the same direction, without any sensible variation.

With a needle thus suspended a variation compass might be very easily constructed, and it would perhaps be more accurate than those commonly in use. For this purpose the needle ought to be about three inches long, and the piece of looking-glass ought to be fixed upon the index of an HADLEY's sextant, which must be placed horizontally under the needle, with its edge or fiducial line in the meridian of the place, in order to observe the daily variation of the needle. I have made only a rough model of such a variation compass, and it seemed to answer very well. This construction appears to have the following advantages over the common sort: 1st, the needle being cylindrical, and without a hole in the middle, would be less subject to have more than two poles. 2dly, The needle being slender, its poles would stand more exactly in its axis, which with the common flat needles is seldom the case. 3dly, It will appear, by a little consideration, that in this construction there is no need of the needle's center of motion keeping always in the same invariable point, which renders the construction both very easy and very accurate: and, lastly, as the sextant may be placed at a considerable distance below the needle, and the rest of the frame may be made of any size, there would be no necessity of placing any brass or other metal so near the needle as might affect it in case this metal had any magnetism, which generally happens with brass.

In order to examine the magnetism of divers substances, besides the above described needle, I used to put a small magnetic needle upon water, and then bring the substance to be examined near it, or place the substance itself upon water, sometimes

sometimes resting it upon pieces of cork, and then bring a powerful magnet near it.

Examination of the Magnetical Properties of Brass.

A few years ago, being intent on making some magnetic experiments, in which brass was concerned, I used to examine first whether the pieces of brass had any magnetism or not, and rejected those pieces which had an evident degree of that power. In the course of those experiments I remember to have observed, that those pieces of brass which had been hammered were generally magnetic, and much more so than others; in consequence of which I made no use of hammered brass in those experiments. But lately, having ordered a theodolite at a philosophical instrument shop, I particularly enjoined the workmen to try the brass, both soft and hammered, before they worked it, and to make no use of that which had any magnetism. They found, that hammered brass, even such as before the hammering had no magnetism, could afterwards disturb the magnetic needle very sensibly. These observations induced me to make the following experiments.

E X P E R I M E N T I.

An oblong piece of brass, weighing somewhat less than half an ounce, being examined by presenting every part of its surface to the suspended needle, shewed no sign of magnetism whatever. It was then hammered for about two minutes; the consequence of which was, that it became magnetic so far as to attract either end of the needle from about a quarter of an inch. This same piece of brass being now put into the fire so as

to become red-hot, by which means it was softened, and when cold being presented to the suspended needle, its magnetism was found to be entirely gone. Hammering made it again magnetic. Softening by fire took the magnetism away a second time; and thus the magnetism was repeatedly given it by hammering, and was destroyed by softening; sometimes shewing to have acquired a sensible degree of that power, even after two or three strokes of the hammer.

EXPERIMENT II.

The result of the first experiment would naturally induce one to suspect, that the hammer and anvil might have imparted some small quantity of steel to the brass, which rendered it magnetic; and that this magnetism was destroyed in softening the brass, inasmuch as the fire calcined the small quantity of steel that had adhered to it. In consequence of which consideration, I took other pieces of brass besides that used before, and hammered them between card-paper, changing the pieces of paper as often as was necessary, since they were easily broken by the hammer; but the pieces of brass became constantly magnetic by the hammering, and their magnetism was destroyed by fire.

In this experiment I generally gave to the brass not above thirty strokes with the hammer.

EXPERIMENT III.

Still suspecting that the hammer and the anvil might have imparted some small quantity of iron to the brass, because the pieces of card-paper sometimes were broken by the first or
second

second stroke, in which case either the hammer or the anvil touched the brass; I hardened a piece of brass by beating it between two large flints, *viz.* using one for the hammer, and the other for the anvil. The piece of brass became magnetic, though in this case it seemed to have acquired not so much power as when it had been hardened with the hammer; but it must be observed, that the flints being rough and irregular, the piece of brass could not be hardened by them so easily, or so equally, as by the other method.

The flints, being examined both before and after the experiment, were found to have not the least degree of magnetism.

EXPERIMENT IV.

A piece of brass, which by hammering had been rendered so strongly magnetic as to attract either pole of the needle from about a quarter of an inch, was put into a crucible, together with a considerable quantity of charcoal dust, which surrounded it every where. The crucible was covered with clay, and being put into the fire, was kept red-hot for about ten minutes. After cooling, the piece of brass was taken out of the crucible, and being examined, was found to have entirely lost its magnetism. The object of this experiment was to ascertain whether the loss of magnetism, in a piece of brass that was softened, was owing to the calcination of the ferrugineous particles, which, notwithstanding the preceding experiments, might still be suspected to be imparted to it; because in this way of softening the brass, the ferrugineous particles being surrounded with charcoal dust, could not have been calcined; hence the brass ought not to have lost its magnetism, which was not the result of the experiment.

E X P E R I M E N T V.

One of those pieces of brass which had been used for the foregoing experiments, and which had been deprived of magnetism by fire, was hammered between two large and pretty thick pieces of copper, which were not in the least magnetic; and, after a few strokes of the hammer, it became sensibly magnetic.

E X P E R I M E N T VI.

In order to examine the difference of this property in brass of various kinds, I have tried a great many pieces of English as well as foreign brass; some of which was very old, and so fine and uniform, that an eminent watch-maker of my acquaintance used it for the very best sort of watch work. But I find, that they mostly have the property of becoming magnetic by hammering, and of losing that power when softened. There are, however, some pieces which acquire no magnetism by the hammering, though they are rendered equally hard by it as those which acquire the magnetism. By attentively examining them, I have not yet been able to distinguish, without a trial, which pieces are capable of acquiring magnetism, and which not; the colour, apparent texture, and degree of ductility seeming to afford no sure indication. In short, what I have observed relating to the magnetic properties of brass is :

1st, That most brass becomes magnetic by hammering, and loses the magnetism by annealing or softening in the fire.

2dly, That the acquired magnetism is not owing to particles of iron or steel imparted to the brass by the tools employed.

3dly,

3dly, Those pieces of brass which have that property, retain it without any diminution after a great number of repeated trials, *viz.* after having been repeatedly hardened and softened. But I have not found any means to give that property to such brass as had it not naturally.

4thly, A large piece of brass has generally a magnetic power somewhat stronger than a smaller piece; and the flat surface of the piece draws the needle more forcibly than the edge or corner of it.

5thly, If only one end of a large piece of brass be hammered, then that end alone will disturb the magnetic needle, and not the rest.

6thly, The magnetic power which brass acquires by hammering has a certain limit, beyond which it cannot be increased by farther hammering. This limit is various in pieces of brass of different thickness, and likewise of different quality.

7thly, Though there are some pieces of brass which have not the property of being rendered magnetic by hammering; yet all the pieces of magnetic brass, that I have tried, lose their magnetism by being made red-hot, excepting indeed when some piece of iron is concealed in them, which sometimes occurs; but in this case, the piece of brass, after having been made red-hot and cooled, will attract the needle more forcibly with one part of its surface than with the rest of it; and hence, by turning the piece of brass about, and presenting every part of it successively to the suspended magnetic needle, one may easily discover in what part of it the iron is lodged.

From those observations it follows, that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned, as dipping needles, variation compasses, &c. the brass should be either left quite soft, or it should be

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chosen of such a sort as will not be made magnetic by hammering, which sort however does not occur very easily.

Examination of the Magnetic Properties of some other Metallic Substances.

The result of the experiments on brass induced me to examine other metallic substances, and especially its components, viz. copper and zinc: though the result of the experiments has not been very remarkable, excepting with platina, which metal has properties in great measure analogous to those of brass.

Having examined various pieces of copper, by means of the suspended magnetic needle, and having never found them magnetical, except only sometimes in such places which had been filed, and where some particles of steel might have been left by the file, I next proceeded to hammer some pieces of it, not only in the usual way, but likewise between flints: the result, however, was very dubious; for though, in general, they had no effect whatever on the needle, yet sometimes I thought the needle was really attracted by some pieces of hammered copper; but then this attractive power was so exceedingly small as not to be depended upon.

Zinc, either not hammered, or hammered as far as could be done without breaking it, shewed no signs of magnetism whatever, when presented to the magnetic needle. A mixture of zinc and tin neither had any action upon the needle.

A piece of a broken reflector of a telescope, which consisted of tin and copper; a mixture of tin, zinc, and a little copper; a piece of silver, both soft and hammered; a piece of pure gold, both soft and hammered; a mixture of gold and silver, both hard and soft; and another mixture of a great deal of
silver,

silver, a little copper, and a less quantity of gold, either before or after hammering, had not the least action on the magnetic needle.

Platina was the metal I last examined, and the experiments made with it seem to deserve particular attention.

EXPERIMENT I.

A large piece of platina, which, after being precipitated from its solution in *aqua regia*, had been fused, or rather concreted together, being presented to the suspended magnetic needle, shewed not the least sign of magnetism. It was then hammered; but after the third or fourth stroke of the hammer it broke into many pieces, several of which being tried, shewed no magnetism, nor could any of the finest particles be attracted by the magnet presented very nearly over them. The broken surface of this piece of platina was full of cavities, some of which were large, and others just discernible; and altogether the metal seemed to have undergone an imperfect fusion.

EXPERIMENT II.

The grains of native platina were examined next, by putting a magnet just over them; but the magnet attracted not above ten or twenty particles out of about half an ounce of platina: and those which were attracted had either little or no shining metallic appearance like the rest, and were exceedingly small.

EXPERIMENT III.

Having picked out several of the largest grains of platina, I presented the magnet to them; but they were not

in the least attracted by it. One of those grains was then hammered; by which means, after about eight or ten strokes, it was spread into a plate, about a tenth of an inch in diameter, and nearly circular; afterwards the magnet being presented to it, the former attracted it from the distance of about one-twentieth of an inch. The other grains being all hammered one after the other, were rendered by it so far magnetic as to be attracted by the magnet, and to disturb the suspended needle when they were presented to it. But there were some amongst them which acquired no magnetism at all, though they had been purposely hammered much longer than the others.

As far as I could observe, those pieces which would not acquire any magnetism by hammering, had not a very shining appearance before the hammering, though afterwards they could not be distinguished from the others by their appearance; and they seemed not to spread under the hammer so easily as the others.

In general three or four strokes are sufficient to render a grain of platina evidently magnetic, but about ten strokes give it the full power it is susceptible of.

EXPERIMENT IV.

Those grains of platina, which in the preceding experiments had been rendered magnetic by hammering, being put upon a charcoal, were made red-hot by means of a blow-pipe; and afterwards being presented to the magnet, and likewise to the suspended needle, they shewed not the least sign of magnetism. Heat, therefore, deprives them as well as brass of the magnetism acquired by hammering. A second hammering rendered them magnetic, though not so quickly, nor to so great a degree,

degree, as it had done the first time. However, it must be observed, that the pieces of platina having been rendered flat and thin by the first hammering, could not be so easily struck, nor spread much more, by the second.

If it is true, as those experiments seem to prove beyond a doubt, that magnetism may exist, or may belong to other substances, independent of iron, it must follow, that the attraction of a few particles of an unknown substance by the magnet is not a sure sign of the presence of iron. Hence those substances, which hitherto have been considered as containing ferrugineous particles, for no other reason but because the magnet attracted a small quantity of them, must be considered as dubious; and the conclusion of the existence of iron should not be admitted, except when those particles, which have been separated by the magnet, appear to be iron by some other trial; for though it is true, that iron is always attracted by the magnet, yet it does not hence follow, that whatever is attracted by the magnet must be iron.

P O S T S C R I P T.

THE existence of magnetism, or of the power of attracting and being attracted by the magnetic needle, in bodies, without the interference of iron or any ferrugineous matter, being a proposition not only new and singular, but seemingly of importance in philosophy, the experiments which tend to confirm it should be never deemed superfluous, nor any possible objection be left unanswered: hence, since the writing of the foregoing paper, I have endeavoured to raise objections, and to con-

trive means of explaining them; but every consideration seemed to confirm the proposition advanced. The principal of those objections was, that the brass which becomes magnetic by hammering and loses that power by softening, might contain a small quantity of iron, to which that magnetic power was owing; and that this iron or martial earth, dispersed through the substance of the brass, might become phlogisticated by the action of hammering; inasmuch as the brass being forced into a smaller space might perhaps give some of its phlogiston to the martial earth, and thus render it magnetic; and, on the contrary, the action of the fire in softening might remove that phlogiston from the martial earth, and give it to the brass; hence the former, remaining quite dephlogisticated, would no longer shew any signs of magnetism. The consideration that iron may be dephlogisticated or calcined more easily than brass gave an apparent weight to the supposition; but the following experiments seem to expel every doubt.

EXPERIMENT I.

Having chosen a piece of brass which would acquire no magnetism by hammering, I placed it upon the anvil, together with a considerable quantity of *crocus martis*, which crocus had no action on the magnetic needle; then began hammering the brass, and turning it frequently, in order to let part of the crocus adhere to it; and, in fact, the crocus had in several places been fastened so well into the brass, that hard wiping with a woollen cloth would not rub it off. The brass appeared red in those places; but, after having been hammered for a long time, it acquired no magnetism whatever. The hardening, there-

fore, could not render the iron calx so far phlogisticated as to affect the magnetic needle.

EXPERIMENT II.

In order to diversify the preceding experiment, I drilled a hole, about one-eighth of an inch long, and little more than one-fiftieth of an inch in diameter, into a piece of brass that was not rendered magnetic by hammering, and filled it with *crocus martis*; then I hammered the piece of brass, thus inclosing the calx of iron, and afterwards presented it to the needle; but there was not the least sign of attraction: the martial earth, therefore, had not acquired any phlogiston from the brass by the action of hammering.

EXPERIMENT III.

The piece of brass mentioned in the preceding experiment, *viz.* with a little calx of iron in it, was put into the fire, and was made quite red-hot, in which state it remained for about three minutes. Then, after cooling, it was presented to the magnetic needle, and this was attracted by the brass only in that place wherein the calx of iron was contained. The action, therefore, of the fire had rendered the martial earth so far phlogisticated as to attract the magnetic needle; hence, if the magnetism of brass was owing to any ferrugineous matter contained in it, a piece of brass ought to become magnetic when softened, which is contrary to the experiments mentioned in this paper.

E X P E R I M E N T I V .

A hole, similar to that mentioned in the second experiment, was drilled into a piece of brass that would not become magnetic by hammering, and into it was put some black calx of iron, which was so far phlogisticated as to be attractable by the magnet, and the hole was closed by a few strokes of the hammer. In consequence of which the piece of brass, when presented to the suspended magnetic needle, would attract it only about that place where the magnetic calx was contained. This attraction was very weak. Then the piece of brass, thus prepared, was put into the fire, and was kept for about six minutes, in a heat very little short of that necessary to melt brass, and after cooling I presented it to the needle, expecting that the fire might have dephlogisticated that calx of iron so far as not to let it act any longer upon the needle; but the attraction appeared to be of the same degree it was before the heating.

It seems, therefore, to be demonstrated, as far as the subject will admit of demonstration, that the magnetism acquired by brass, when hammered, is not owing to iron contained in it; and, consequently, that *magnetism, or the power of being attracted by, and attracting, the magnet, may exist independent of iron.*

TO DR. BLAGDEN, SEC. R. S.

S I R,

Windfor, January 9, 1786.

I HAVE made the experiment which you recommended me to try, relating to the magnetism of brass; *viz.* I mixed, by means of the blow-pipe, a small quantity of iron, with about four times its weight of such brass as would not become magnetic by hammering. The whole globule weighed about two grains, and it attracted the magnetic needle very powerfully. I then melted this globule of brass and iron with about fifty grains of the same sort of brass as had been used before. After cooling, the whole lump of brass appeared to have very little power upon the magnetic needle, every part of its surface attracting one end of the suspended needle, so as to let it just adhere to it when the air was not at all disturbed. But this weak and hardly perceivable degree of magnetism was not increased by hammering, nor annihilated by softening.

In the course of my experiments on the magnetism of brass, I have twice observed the following remarkable circumstance. A piece of brass, which had the property of becoming magnetic by hammering, and of losing the magnetism by softening, having been left in the fire till it was partially melted, I found, upon trial, that it had lost the property of becoming magnetic by hammering; but having been afterwards fairly melted in a crucible, it thereby acquired the property it had originally, *viz.* that of becoming magnetic by hammering.

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I have likewise often observed, that a long continuance in a fire so strong as to be little short of melting hot, generally diminishes, and sometimes quite destroys, the property of becoming magnetic in brass. At the same time, the texture of the metal is considerably altered, becoming what some workmen call *rotten*. From this it appears, that the property of becoming magnetic in brass by hammering, is rather owing to some particular configuration of its parts, than to the admixture of any iron; which is confirmed still farther by observing, that Dutch plate-brass (which is made not by melting the copper, but by keeping it in a strong degree of heat whilst surrounded by *lapis calaminaris*) also possesses that property; at least all the pieces of it, which I have tried, have that property.

I am, &c.

T. CAVALLO.

